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Assessment of Ambient Air Quality at Gajuwaka Industrial Hub in Visakhapatnam using IND-AQI method

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Abstract— **Air pollution is projected as one of the major environmental issues as it risks the health of humans by spoiling air quality. Hence, air quality indices have been considered by many researchers as a simple and understandable way to measure the air quality with respect to its effects on human health. In this context, we collected a total of 168 ambient air samples in winter and summer seasons at seven points in selected residential areas of the Gajuwaka industrial hub. The measured data of six criteria air pollutants such as RSPM, TSPM, SO_2, NO_x, NH_3 and Pb were converted into an Indian air quality index (IND-AQI) recently developed by CPCB, New Delhi to study the status and seasonal variation of the air quality. The results revealed that the seasonal mean of air quality index values was varied from 60.2 to 143.3 and 82.8 to 226.5 in winter and summer seasons respectively. Gaseous pollutants and RSPM values were found to be higher in winter compared to summer season whereas TSPM values are high in summer with respect to winter season. It has been observed that on the basis of IND-AQI scale, the study area has fallen under 'moderate' category with the annual mean value of 118.4 The study indicated that total suspended particulate matter (TSPM) was mainly responsible for air pollution (92.9%) in this area during the study period and became a critical pollutant in the majority of the sampling points followed by RSPM. Further, the calculated Exceedence factors were also confirmed the deterioration of air quality in the study area as moderate to high pollution category with TSPM as a critical pollutant. Increasing trends of air pollution were observed consistently during the study period at all the locations.**

Index Terms—**Air quality index, Critically polluted, Exceedence factor, Industrial activities, Human health, Particulate matter.**

I. INTRODUCTION

Visakhapatnam bowl area was declared as one of the critical [1], [2] and severely [3] polluted areas in the country with the CEPI scores of 70.82 (in 2009) and 52.31 (in 2013) respectively owing to its vast industrial and port related activities with typical topography and meteorological conditions. But unending urban sprawl with relentless industrial activities and vigorous vehicular movement has resulted in severe air pollution problems outside the bowl area too. Gajuwaka a sub-urban area located on the southern side of the Visakhapatnam city is topographically not in the bowl area. However it was also emerging as a major industrial hub with a cocktail mix of major and minor industries including a minor port posing significant threat to the environment, quality of life and health of the residents. The concentration of air pollution can vary considerably from one location to another as they depend not only on the quantity that are emitted but also on the atmospheric conditions such as temperature, wind speed and direction [4]. The topographical features, wind movement especially due to land and sea breeze, this area experiences the different trends of pollutant dispersal conditions. This results in marked variations in concentration and exposure time of the pollutants. Viewed in this backdrop, we attempted to evaluate a comprehensive study of the status of air quality by considering the six criteria air pollutant concentration with USEPA health related index, based on the guidelines of Indian air quality index (IND-AQI) and seasonal variations at the residential colonies located closer to the Gajuwaka industrial hub. This not only gives an insight into the current status of air quality in the study area but also helps in identifying and prioritizing the future studies and regulatory plans to overcome the problems now bothering in the bowl area people of Visakhapatnam city.

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A. Topography and prevailing meteorology of Study area:

The villages and colonies of Gajuwaka industrial hub which is located on the south of Visakhapatnam city in between 17^0 34'00" N to 17^0 42'00" N latitudes and 83^0 07'00" E to 83^0 14'00" E longitudes were chosen for the present study. The study area has seen rapid industrialization and tremendous population growth during the last few decades. The study area is encompassed with a thermal power plant, an upcoming pharma city, an integrated steel plant, a minor port, a number of associated ancillaries and bound in the east by the Bay of Bengal. Kolkata - Chennai National Highway-16 passes through this area. The topography of the area is from plain to undulating with small hillocks. Yarada hill range stretches from E to WNW and NW of the study area with a maximum altitude of about 360m. The climate is warm and humid. This area experiences two spells of rainfall during the southwest and northeast monsoons. And also this area is subjected to on an average two to three low pressure depressions (sometimes intensified to cyclonic storms) which results in moderate to heavy rains. The winds are north-northeasterly during the winter season while during the summer they are west-southwesterly. Wind speed is quite high with the predominant wind direction of WSW followed by W and SW. It is also noticed that, at low winds or calm conditions, sea breeze to landwards dominate within the study area. Hence, there is a possibility of buildup of pollutant levels in the study area owing to low ventilation coefficient.

II. METHODOLOGY

Keeping in view the sensitive nature of the situation, ambient air quality monitoring was carried out at seven residential areas (Table-I and Fig.1) during winter and summer seasons for a period of two years (2008-2010). The locations of the monitored points were selected primarily in residential areas of higher population density with due consideration to terrain features and local meteorological conditions. A total of six criteria air pollutants such as RSPM (PM_{10}), TSPM, SO_2, NO_x, NH_3 and Pb in ambient air were measured for 24 hrs average in the present study. Standard procedures recommended by the IS: 5182 [5] and Intersociety Committee [6] for the sample collection, handling, preservation and analysis were followed to ensure data quality and consistency. The air quality index (AQI) is a widely used concept to communicate with the public on air quality [7] to understand easily that how bad or good for their health and to assist in data interpretation in decision making processes related to pollution mitigation measures and environment management [8]. For the calculation of air quality index, we adopted the health related index method of the USEPA-AQI [9] in which sub index and breakpoint pollutant concentrations depend on the Indian Air Quality Index proposed by the Central Pollution Control Board (http://home.iitk.ac.in/~mukesh/air-quality/Basis.html) New Delhi. Further, Central Pollution Control Board defined Exceedence Factors (EF) were also calculated to categorize the air pollution and to assess the most critical pollutant among other pre-identified parameters [2].

Table – I. Sampling locations of ambient air samples

Sl. No.	Sampling point	Location of the sampling point
1.	AA-1	N 17^0 38' 66.5" E 83^0 13' 52.3"
2.	AA-2	N 17^0 39' 90.3" E 83^0 12' 35.1"
3.	AA-3	N 17^0 40' 72.4" E 83^0 12' 94.0"
4.	AA-4	N 17^0 40' 58.8" E 83^0 10' 99.8"
5.	AA-5	N 17^0 41' 42.2" E 83^0 10' 38.2"
6.	AA-6	N 17^0 38' 43.7" E 83^0 07' 44.2"
7.	AA-7	N 17^0 34' 59.7" E 83^0 10' 40.0"

As winter and summer seasons were considered as typical seasons for evaluation; the data of mean, maximum and minimum of atmospheric temperature, relative humidity, wind speed, annual rainfall (Table–II), wind direction and wind roses (Fig.2a and 2b) were collected from the weather monitoring station located in the study area.

A. *Computation of Indian Air Quality Index (IND-AQI):*

The air quality index includes sub-indices which relate ambient pollutant concentrations to index values on a scale from 0 to 500. The segmented linear function was used for relating the actual air pollution concentrations (of each pollutant) to a normalized number (sub-index). The sub-indices for each of the pollutants were obtained from the formula specified by USEPA (given below) using their respective breakpoints and associated IND-AQI values proposed by the Central Pollution Control Board (Table-III). Having calculated sub-index of each pollutant, the overall Indian air quality index was based on maximum operator concept where the maximum value of the sub-index becomes the Indian air quality index. To reflect the status of air quality, the range of Indian air quality index values has been categorized by Sharma et al. 2003 as good (0-100); moderate (101-200); poor (201-300); very poor (301-400) and severe (401-500) as shown in Table–III.

$$AQIp = \{(AQIPc\ high - AQIPc\ low) / (Pc\ high - Pc\ low)\} \times (Pc - Pc\ low) + AQIPc\ low$$

Where,

AQIp = the sub-index for the pollutant, p
Pc = the rounded concentration of the pollutant, p
Pc high = the high breakpoint concentration, (≥Pc)
Pc low = the low breakpoint concentration, (≤Pc)
AQIPc high = the AQI value corresponding to Pc high,
AQIPc low = the AQI value corresponding to Pc low.

The higher value of an index refers to a greater level of air pollution and consequently greater health risks. Indian air quality index values below 100 are generally thought of as satisfactory. When Indian air quality index values are above 100, air quality is considered to be unhealthy-at first for certain sensitive groups of people, then for everyone as Indian air quality index values get higher. Effects on human health with respect to air quality index range, along with the cautionary statement were given in Table-IV.

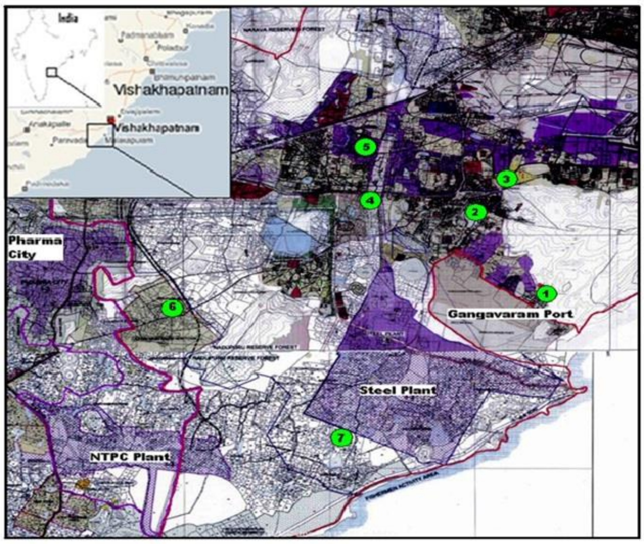

Fig.1: Map showing location of sampling points along the study area

B. *Computation of Exceedence Factor (EF):*

Exceedence Factor (EF) =
Observed annual mean concentration of a criteria pollutant / Annual standard of the respective pollutant for specific area.

The four air quality categories are:

- Critical pollution (C): when EF is more than 1.5;
- High pollution (H): when the EF is between 1.0 - 1.5;
- Moderate pollution (M): when the EF between 0.5 - 1.0 and
- Low pollution (L): when the EF is less than 0.5.

Table – II. Annual statistics of meteorological parameters

Year & Meteorological Parameters	Weather - 2008			Weather - 2009			Weather -2010		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
Temperature (^{0}C)	26.3	38.1	15.0	29.9	43.7	17.8	27.3	40.4	13.5
Relative Humidity (%)	81.8	97.0	23.0	78.0	98.0	0.0	75.1	86.0	29.0
Wind Speed (km/hr)	4.6	17.1	0.0	4.5	18.9	0.0	6.0	26.3	0.0
Annual Rainfall (mm)	1314.1			795.5			2043.5		

Wind roses representing at the study area

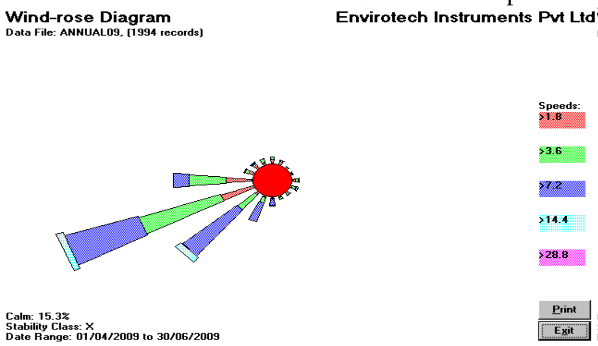

Fig. 2a summer (Apr-09 to Jun-09)

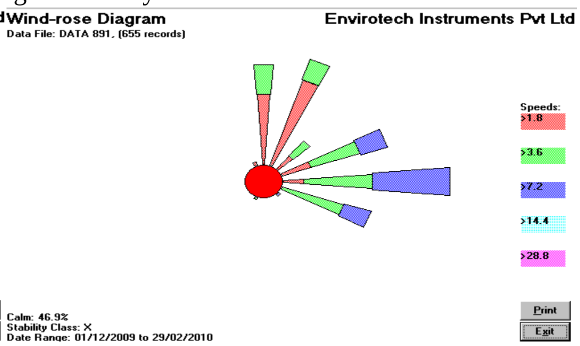

Fig. 2b winter - (Dec-09 toFeb-10)

Table – III. Proposed sub-index and breakpoint pollutant concentrations for IND-AQI

Sl. No	Sub-index value	Category	24hr. avg. (µgm/m^3)					
			SO_2	NO_2	SPM	PM_{10}	NH_3	Pb
1.	0-100	Good	0–80	0–80	0-200	0-100	0-60	0-1
2.	101-200	Moderate	81-367	81–180	201-260	101-150	61-90	1-1.5
3.	201-300	Poor	368-786	18–564	261-400	151-350	91-210	1.5-2.25
4.	301-400	Very Poor	787-1572	565– 1272	401-800	351-420	211-250	2.25-3.25
5.	401-500	Severe	>1572	>1272	>800	>4200	>250	>3.25

Source: Basis of Indian Air Quality Index.

Table – IV. Health alert description of IND-AQI

IND-AQI range	Category	Cautionary statement
0-100	Good	Air quality is considered satisfactory and air pollution poses little or no risk.
101-200	Moderate	*Sensitive people who are with respiratory disease are at greater risk.
201-300	Poor	Everyone may begin to experience health effects. *Sensitive people may experience more serious health effects.
301-400	Very Poor	This range triggers a health alert, meaning everyone may experience more serious health effects.
401-500	Severe	This range triggers health warnings of emergency conditions. The entire population is more likely to be affected.

** Sensitive people include children, the elderly people and the people those with existing health conditions.*

III. RESULTS AND DISCUSSION

A. Variation of air quality sub-indices at the study area:

The season-wise variation of the air quality sub-indices of the six criteria pollutants in terms of average, maximum and minimum were depicted in Table-V. The average range of air quality sub indices of RSPM, TSPM, SO_2, NO_x, NH_3 and Pb in all the seven sampling points were in between 44.0-103.8, 56.6-226.5, 17.8-44.4, 24.5-61.9, 0-69.3 and 7.9-19.2 respectively indicated that except RSPM and TSPM all the other pollutants were fallen under 'good' category and these were not critical pollutants in the study area during the entire study period. Further, the results revealed that the average values of TSPM sub indices were categorized as 'good' in 50.0% of observations during the study period followed by 42.9% as 'moderate' and the remaining 7.1% under 'poor' category. About 96.4% of the observations, RSPM was in 'good' category. These observations were corroborated the findings made in the city of Bangalore [10]. The highest and lowest averages of TSPM sub-indices were observed at sampling point AA-1 and AA-5 respectively indicated that these two points are the highly polluted and pollution free areas respectively compared to the rest of the sampling points during the study period in the entire study area.

Table-V. Season-wise average, maximum and minimum of air quality sub-indices

Sampling point	Season / Parameter	Winter '08			Winter '09			Summer '09			Summer' 10		
		Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
AA-1	RSPM	73.9	91.8	58.4	95.7	131.9	74.4	60.2	78.6	52.9	74.6	90.4	58.2
	TSPM	75.1	92.1	60.2	143.3	218.0	97.3	175.7	219.6	132.5	226.5	259.2	209.5
	SO_2	22.6	28.3	18.3	34.0	49.3	24.0	17.8	20.3	16.9	23.8	32.6	19.9
	NO_x	32.5	47.8	25.3	44.4	62.3	32.8	24.6	27.8	22.3	30.1	42.9	23.6
	Ammonia	30.5	36.7	23.3	31.3	40.0	21.7	66.0	80.0	43.3	69.3	86.7	46.7
	Lead	14.1	14.6	13.4	14.7	15.7	13.7	18.1	19.8	15.4	17.3	19.2	15.9
AA-2	RSPM	60.2	74.6	46.8	77.3	103.2	56.2	48.5	73.7	38.1	57.5	73.0	40.4
	TSPM	56.6	67.8	49.9	96.9	173.8	69.8	105.2	149.2	87.6	167.9	262.8	79.5
	SO_2	20.9	27.3	16.9	26.8	45.5	17.9	18.3	21.0	16.9	19.8	22.4	17.4
	NO_x	41.9	58.0	30.1	38.8	52.9	30.1	36.4	39.5	32.0	30.5	43.4	24.8
	Ammonia	22.2	30.0	16.7	23.3	26.7	16.7	53.8	70.0	26.7	55.5	70.0	33.3
	Lead	14.7	15.7	13.6	16.4	18.2	14.9	18.5	20.1	15.7	18.4	19.9	16.0
AA-3	RSPM	103.8	144.6	84.1	99.3	138.8	85.3	53.9	63.2	44.6	54.7	67.2	43.2
	TSPM	98.8	154.4	87.6	116.8	186.2	92.1	168.6	205.8	118.4	212.0	233.3	191.8
	SO_2	38.5	55.1	30.3	44.4	57.9	37.6	28.1	33.9	23.8	24.4	29.5	21.9
	NO_x	53.3	66.5	42.8	61.9	84.9	52.9	45.0	49.5	38.0	38.8	47.6	34.5
	Ammonia	60.0	80.0	46.7	53.8	73.3	36.7	33.8	46.7	23.3	31.7	46.7	23.3
	Lead	18.3	19.9	17.0	19.2	20.9	18.0	16.0	18.1	14.9	17.0	18.8	15.7
AA-4	RSPM	62.7	73.8	55.6	74.2	91.3	53.0	44.0	62.1	29.8	44.8	69.7	30.3
	TSPM	80.0	91.3	70.9	87.3	113.9	73.1	93.0	107.5	80.4	106.7	162.7	94.8
	SO_2	24.5	34.1	20.5	28.3	37.6	23.3	18.5	21.5	16.9	19.8	24.0	17.3
	NO_x	35.3	45.9	28.9	44.5	52.3	37.6	26.0	30.9	22.5	30.0	38.4	24.6
	Ammonia	17.3	20.0	0.0	20.0	23.3	0.0	18.3	20.0	0.0	0.0	16.7	0.0
	Lead	11.8	13.5	10.6	12.6	13.8	12.0	14.9	15.9	13.7	14.7	15.5	13.4
AA-5	RSPM	58.1	71.4	44.6	66.6	78.2	54.8	49.0	56.4	43.8	56.4	66.9	48.2
	TSPM	74.6	90.9	62.0	79.8	101.4	67.6	82.8	89.8	76.5	105.7	133.6	88.3
	SO_2	25.0	35.9	21.0	28.3	39.5	23.3	19.5	23.3	16.9	19.6	24.8	16.1
	NO_x	34.4	43.3	29.8	43.8	55.3	32.6	26.8	31.5	23.0	28.6	34.5	24.8
	Ammonia	27.2	36.7	16.7	27.3	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Lead	12.4	13.6	11.2	12.1	13.4	11.0	12.2	13.4	11.1	12.3	13.0	11.9
AA-6	RSPM	77.6	94.2	63.9	85.7	102.4	66.4	56.6	82.4	39.2	58.9	80.1	41.6
	TSPM	89.5	134.4	76.3	96.8	140.3	79.5	133.4	145.3	101.7	167.4	190.9	145.0
	SO_2	30.9	45.1	22.9	36.9	52.9	27.1	20.4	25.1	16.9	19.5	22.9	16.9
	NO_x	40.6	56.1	30.1	53.3	70.8	40.8	27.9	35.9	22.8	24.5	27.1	22.3
	Ammonia	25.5	33.3	16.7	26.2	30.0	20.0	17.8	20.0	0.0	20.0	20.0	0.0
	Lead	13.7	15.9	12.2	14.6	17.1	13.0	9.4	10.6	8.2	10.0	11.4	9.0
AA-7	RSPM	76.8	87.3	70.2	75.2	83.3	69.8	54.7	68.7	46.9	59.3	63.7	53.2
	TSPM	95.0	112.4	84.1	94.1	108.9	86.0	126.3	155.4	100.1	150.8	173.5	128.5
	SO_2	34.5	48.0	26.0	35.5	45.9	29.0	20.3	26.3	17.3	20.1	25.1	16.9
	NO_x	46.5	58.5	38.4	47.5	56.4	40.1	27.8	37.4	23.3	31.5	42.6	23.6
	Ammonia	34.3	40.0	26.7	31.0	40.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0
	Lead	17.2	20.4	15.6	18.5	21.0	16.4	8.4	9.9	7.2	7.9	9.3	6.8

B. Seasonal trends of air quality:

The seasonal trends of Indian air quality index values of the sampling points in the study area were shown in Fig. 3. The data revealed that all the sampling points of the study area were showing increasing trends of air pollution. The observed pattern of an increasing trend in season-wise is as follows: summer '10 > summer '09 > winter '09 > winter '08 (Fig. 3). Similar observations were made in the study of seasonal variation in ambient air of Durg city [11]. It is observed that almost all the sampling points coming under 'good' category during the season of winter'08. But a drastic change in index values was observed in next immediate season (summer'09) at all the sampling points with a maximum 134% of the increase at AA-1 followed by AA-2 with 85.9% and at AA-3 with 70.6% indicated that severe deterioration of air quality in the study area. Moreover the same increasing trends were observed for the seasons of winter'09 to summer'10 at the sampling points with a maximum 81.5% of the increase at AA-3 followed by AA-2 with 73.3% and at AA-7 with 72.2% indicated alarming situations in the study area. The reason might be the increased activities of industries and vehicular movement. With this it could be assumed that the air pollution level in the near future in the study area becomes a big threat to both human health and the environment. The data revealed that RSPM and gaseous pollutants such as SO_2, NO_x, NH_3, Pb, at all the sampling points in the study area were showing higher values of sub-indices in winter season than in summer season except at sampling point 1 and 2 for NH_3, Pb and at sampling point 4 for Pb which were showing high in summer season than winter (Table-V). This can be attributed to the prevailed calm conditions of 46.9% at the study area in winter season. A study on impacts of meteorological parameters on air pollution in Balikesir, Turkey was also resulted similar observations [12]. In case of TSPM, higher values were

observed in summer season than in winter which was due to prevailing strong winds with mean speed of 4.5 – 6.0 km/hr at the study area in summer. CPCB studied the seasonal variations of air pollution at residential colonies of Delhi and found similar observations [13].

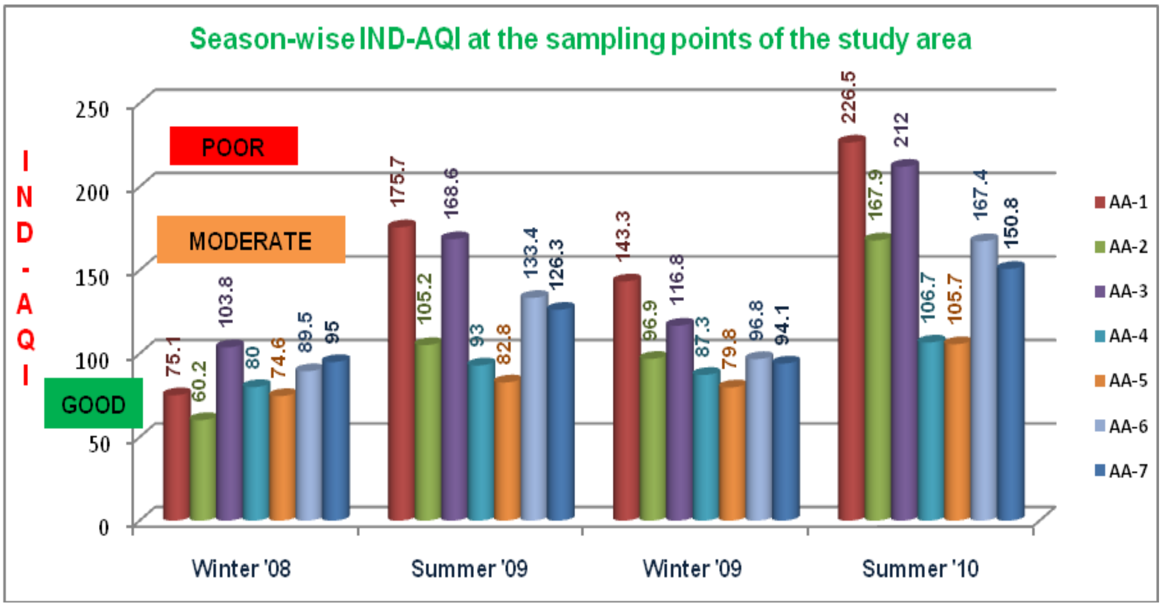

Fig.3 Seasonal trends of IND-AQI at the sampling points of the study area

C. Status of air quality at the study area:

Table-VI depicted the summary of season-wise IND-AQI values with a health alert for the sampling points in the study area. It is observed that the overall Indian air quality indices were found to fall under the category of good and moderate-to-poor due to RSPM and TSPM. The data revealed that 71.4% of the sampling points come under good to moderate category and 14.3% of the sampling points contributed moderate to poor category and the rest are contributed good-to-moderate-to-poor category. Similar observations were made to the air quality at the residential colonies of Ahmedabad city as moderate to unhealthy conditions [14]. Reddy et al. 2004 reported poor to dangerous categories in the residential areas of Visakhapatnam city by applying Oak Ridge air quality index method [15]. From the data it could be inferred that the percentage of annual increase of air quality indices was observed high at all the sampling points with a maximum 38.9 % at AA-2, followed by 32.2% at AA-1. According to recent estimates of UNEP, globally around 1.1 billion people breathe unhealthy air and 8,000 people die every day from diseases related to air pollution exposure [16]. It is found that the air quality of the study area was influenced by TSPM (92.9%) and followed by RSPM. The above findings revealed that TSPM was mainly responsible for the deterioration of air quality in the entire study area and emerged as a critical pollutant in majority of the sampling points. Prakash Mamta and Bassin, 2010 also reported SPM as critical pollutant in the residential areas of Delhi [17]. From the data (Table-6) it is observed that the entire study area was falling under 'moderate' category with the index value of 118.4. This value is compared with the average air quality index value (191.21) of the residential zone of Lucknow city [18] and good to moderate categories were found in the areas around the industrial cluster in Malaysia [19].

D. Comparison of results with that of similar studies of Visakhapatnam bowl area:

With a view to assess the air quality in the study area, our results were compared with the values that of earlier studies conducted in the Visakhapatnam bowl area [1]. We compared the values (mean, maximum and minimum) of Gajuwaka sampling point of NEERI study with our AA-3 sampling point which was also located in Gajuwaka. For clear and easy interpretation, Gajuwaka sampling point analysis values (winter 2002-03) of the NEERI report were converted into Indian air quality sub-indices and categorized the average and maximum final index values as 'good' and 'moderate' respectively (Table-VII). Also, it is observed that particulates are the critical pollutants in both the studies with low gaseous pollutants. The increased levels of all the pollutants except lead were observed in the present study compared to the NEERI study. Consequently, the pollution category was shifted from 'good' to 'moderate' (Table-VII). The decreased level of lead might be because of closure of lead smelter located near the study area in 2001 in addition to switch over to unleaded petrol for vehicles under the compulsion of Bharat stage standards.

Further, to ascertain the air quality indices in the study area we compared with the values of studies conducted by Reddy et al. 2004 on the air quality of the Visakhapatnam bowl area by applying the Oak Ridge air quality index method using three primary pollutants [15]. The annual mean of ORAQI of the entire bowl area was calculated as 41.8 and categorized as 'fair'. This was corroborated the annual mean of Indian air quality index value 118.4 (moderate) at the outside bowl area of Visakhapatnam. To get rid of the ambiguity between the differences in the indices, we converted our results (winter'08 and summer'09) of AA-3 sampling point (Gajuwaka) which is a common location for both the studies into air quality index by applying the Oak Ridge air quality index method. And found that the index values during the winter season were 61.6

(poor) and 55.8 (fair) for earlier study and present study respectively. In case of the summer season, these values were 55.5 (fair) and 59.7 (fair) for earlier study and present study respectively. Despite substantial efforts to bring improvements in air quality during recent times at state and national level, air pollution still remains a significant concern for most of the Indian cities [20].

Table-VI. Seasonal categorization of Indian air quality indices of sampling points in the study area with health alert

Sampling Point	Season	IND-AQI	Category	Critical Pollutant	*Health alert
AA-1	Winter '08	75.1	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '09	175.7	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Winter '09	143.3	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Summer '10	226.5	Poor	TSPM	Significant aggravation of symptoms in susceptible persons and mild aggravation of symptoms in healthy population
AA-2	Winter '08	60.2	Good	RSPM	No measure ill effects are associated with the air quality in this range.
	Summer '09	105.2	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Winter '09	96.9	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '10	167.9	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
AA-3	Winter '08	103.8	Moderate	RSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Summer '09	168.6	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Winter '09	116.8	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Summer '10	212.0	Poor	TSPM	Significant aggravation of symptoms in susceptible persons and mild aggravation of symptoms in healthy population
AA-4	Winter '08	80.0	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '09	93.0	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Winter '09	87.3	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '10	106.7	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
AA-5	Winter '08	74.6	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '09	82.8	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Winter '09	79.8	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '10	105.7	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
AA-6	Winter '08	89.5	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '09	133.4	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Winter '09	96.8	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '10	167.4	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
AA-7	Winter '08	95.0	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '09	126.3	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
	Winter '09	94.1	Good	TSPM	No measure ill effects are associated with the air quality in this range.
	Summer '10	150.8	Moderate	TSPM	Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.
Study area average		118.4	Moderate	TSPM	**Mild aggravation of symptoms in susceptible persons. Short term exposures result in irritation symptoms in healthy persons.**

* Source: http://home.iitk.ac.in/~mukesh/air-quality/Basis.html

** Susceptible persons: Persons with heart or lung diseases.

Table-VII. Comparison of results with the earlier reports of NEERI (similar sampling location)

Sampling point		Winter '08-09			Sampling point		Winter '02-03		
Sampling point AA-3 located in Gajuwaka area (present study)	Parameter	Avg.	Max.	Min.	Sampling point located in Gajuwaka (studied by NEERI, 2005)	Parameter	Avg.	Max.	Min.
	RSPM	103.8	144.6	84.1		RSPM	75.1	125.2	46.0
	TSPM	98.8	154.4	87.6		TSPM	72.0	98.0	51.0
	SO_2	38.5	55.1	30.3		SO_2	9.9	18.8	7.5
	NO_x	53.3	66.5	42.8		NO_x	9.5	16.3	5.0
	Ammonia	60.0	80.0	46.7		Ammonia	39.0	66.7	8.3
	Lead	18.3	19.9	17.0		Lead	24.5	27.4	21.6
	IND-AQI	103.8	154.4	87.6		IND-AQI	75.1	125.2	51.0
	Category	**Moderate**	Moderate	Good		Category	**Good**	Moderate	Good

E. Exceedence factors of the study area:

The Exceedence factors for each pollutant at all sampling points were given in Table-VIII. From the results it is found that all the gaseous pollutants were categorized as 'low' for all the sampling points during the entire study period and it was also corroborated the Indian air quality sub-indices calculated (Table-V). In case of RSPM at all the sampling points, 'moderate' pollution category was observed all the time of the study period. When this has coupled with the Indian air quality index values of the study period, it is found that 'moderate' category was observed in only 3% of the study period. Senthilnathan, 2007 reported similar observations in Chennai city urban ambient air quality studies [21]. It is revealed from the observations that the TSPM values have emerged as a critical pollutant at all the sampling points with maximum Exceedence factor at sampling point AA-1 as 1.4 followed by AA-3 as 1.2 and at AA-2 as 1.1. The Indian air quality index values were also depicted the same version of TSPM as a critical pollutant in 92.9% of observations. The data revealed that for the period of 2008-09, 'moderate' pollution categories was observed for all the sampling points except at AA-3 which reported the pollution category as 'high'. From the annual data of 2009-10, 'moderate' pollution categories were observed for all the sampling points except at sampling points AA-1, AA-2, AA-3 and AA-6 as 'high' pollution category. Moderate (0.78) and high pollution (1.14) categories were reported for SPM and RSPM at Pantnagar industrial estate [22].

Table-VIII. Exceedence factors and pollution categorization of the study area

Location	Year	RSPM	Pollution Category	TSPM	Pollution Category	SO_2	Pollution Category	NO_x	Pollution Category	Ammonia	Pollution Category	Pb	Pollution Category
AA-1	2008-09	0.8	Moderate	0.9	Moderate	0.3	Low	0.4	Low	0.0	Low	0.3	Low
	2009-10	0.7	Moderate	**1.4**	**High**	0.2	Low	0.3	Low	0.1	Low	0.4	Low
AA-2	2008-09	0.7	Moderate	0.8	Moderate	0.2	Low	0.4	Low	0.0	Low	0.3	Low
	2009-10	0.5	Moderate	**1.1**	**High**	0.2	Low	0.3	Low	0.1	Low	0.4	Low
AA-3	2008-09	0.8	Moderate	**1.1**	**High**	0.3	Low	0.5	Low	0.1	Low	0.3	Low
	2009-10	0.8	Moderate	**1.2**	**High**	0.3	Low	0.5	Low	0.1	Low	0.4	Low
AA-4	2008-09	0.5	Moderate	0.9	Moderate	0.2	Low	0.3	Low	0.0	Low	0.3	Low
	2009-10	0.6	Moderate	0.9	Moderate	0.2	Low	0.4	Low	0.0	Low	0.3	Low
AA-5	2008-09	0.5	Moderate	0.8	Moderate	0.2	Low	0.3	Low	0.0	Low	0.2	Low
	2009-10	0.6	Moderate	0.9	Moderate	0.2	Low	0.4	Low	0.0	Low	0.2	Low
AA-6	2008-09	0.7	Moderate	1.0	Moderate	0.3	Low	0.3	Low	0.0	Low	0.2	Low
	2009-10	0.7	Moderate	**1.1**	**High**	0.3	Low	0.4	Low	0.0	Low	0.2	Low
AA-7	2008-09	0.7	Moderate	1.0	Moderate	0.3	Low	0.4	Low	0.1	Low	0.3	Low
	2009-10	0.7	Moderate	1.0	Moderate	0.3	Low	0.4	Low	0.0	Low	0.3	Low

Thus the increasing trends of air pollution in the study area were proved to be in agreement of both Indian air quality index values and Exceedence factors calculated.

F. Pollutants dispersal conditions with respect to meteorological parameters at the study area:

The seasonal wind roses related to the study area were shown in Fig. 2a and b. The prevailing wind direction with strong winds in the study area shows west, west-southwest and southwest direction in maximum period of the year which is towards the Bay of Bengal influences the dispersion of pollutants towards the sea and the wind direction with low speed winds from east, northeast in winter season builds up the pollutants at the sampling points (Fig. 2a and b). The mixing heights of this study area which enhances the spread of pollutants were influenced by the intensity of sea and land breeze circulations in summer season. It could be seen that overall air quality indices at the study area were higher in summer seasons and decreasing to some extent in winter seasons. The decreasing trend of summer season to winter season could be attributed to the wash out of the pollutants by mean annual rainfall of 1384mm (wet deposition) at the study area. The low depression oriented (aseasonal) rainfall in addition to seasonal rainfall in the study area increases the wash out of aerosols and improves the quality.

IV. CONCLUSION

The study area is witnessing a gradual increase of air pollutants from season to season and year to year reaching to severe air pollution conditions by which the human health is affected in this area. Particulate pollution is more severe than the gaseous pollutants in the study area. It is influencing by the meteorological conditions of the study area which in turn escalates the problem of air pollution within no time. Overall not much difference is seen between the bowl area and outside bowl area (study area) as per as the particulate pollution is concerned. Remedial actions are to be taken up by the concerned agencies with long range planning.

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